E 7 5 - 1 0 3 0 8.

CR-142852

APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF LAKE EUTROPHICATION IN THE GREAT LAKES BASIN

Robert H. Rogers
Bendix Aerospace Systems Division
3621 South State Road
Ann Arbor, Michigan 48107

June 1975
Type II Report for the Period of March through May of 1975

(E75-10308) APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF LAKE EUTROPHICATION IN THE GREAT LAKES BASIN Progress Report, Mar. - May 1975 (Bendix Corp.) 41 p HC $3.75 CSCL 08H G3/43

N75-25255

Unclas 00308

Prepared for:

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Application of LANDSAT to the Surveillance and Control of Lake Eutrophication in the Great Lakes Basin		5. Report Date June 1975
		6. Performing Organization Code
7. Author(s) Robert H. Rogers		8. Performing Organization Report No. BSR 4183
9. Performing Organization Name and Address Bendix Aerospace Systems Div. 3621 South State Rd Ann Arbor, Mich. 48107		10. Work Unit No.
		11. Contract or Grant No. NAS5-20942
		13. Type of Report and Period Covered Type II March - May 1975
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Md. 20771		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This paper reports on the results achieved during the first three months to establish cost benefits of LANDSAT for the surveillance and control of lake eutrophication. This goal is being accomplished by producing LANDSAT products for an EPA modeling study of Saginaw Bay and inland lake surveys by the Michigan and Wisconsin DNRs. These user agencies are, in-turn, providing detailed ground truth on water quality and are participating in studies and evaluations to determine the cost benefits of LANDSAT.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water quality, land-use, computer processing, lake eutrophication, ERTS, and LANDSAT	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

PREFACE

Program Objectives

The overall objective of this investigation is to establish the cost benefits of using LANDSAT on an operational basis in the surveillance and control of lake eutrophication. This objective is accomplished by supporting, with LANDSAT data products, bona fide users who will evaluate the data's usefulness to on-going programs concerned with the classification and control of lake eutrophication. The products supplied to the users will be made as applicable as possible to their data needs. The following, therefore, are specific objectives to be addressed:

1. To identify the data requirements of the users and to relate these to LANDSAT data with respect to land-water categories, detail, scale, and frequency.

2. To identify water quality parameters which relate directly to eutrophication and to determine quantitative levels of these parameters by which lakes may be categorized as to trophic state.

3. To identify land-use patterns which relate to trophic state.

4. To develop and apply LANDSAT data interpretation techniques to categorize water and land-use features identified in order to produce information products of value to users.

Scope of Work

This investigation is supplying LANDSAT-derived information products to three federal and state agencies which are involved in the planning and management of lakes and watershed land use in the Great Lakes basin. Support will be provided to the Environmental Protection Agency modeling study of lake eutrophication in Saginaw Bay; the State of Michigan Department of Natural Resource Survey of inland lakes and watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution due to land-use practices; and the State of Wisconsin Department of Natural Resources lake survey to determine eutrophication status, causes, effects, and control treatments. For each of these three programs, this investigation will analyse and interpret LANDSAT data to provide the three user agencies with land-use and lake water quality information about their specific test areas. The usefulness of LANDSAT data to each type of study and the cost benefits of its use over alternative data collection systems will be evaluated.

Conclusions

Preliminary results in Saginaw Bay show that processed LANDSAT data provides a synoptic view of turbidity and circulation patterns that no degree of ground monitoring can provide. Processed imagery was produced to show nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. Further processing will determine other water quality parameters that can be mapped and the amount of point sampling needed.

Analysis of lakes near Madison, Wisconsin show that inland lake water can be categorized by LANDSAT as clear, tannin, algal, and red clay. Further subdivisions seem feasible.

LANDSAT's capability to inventory watershed land use has now been thoroughly demonstrated in the Ohio-Kentucky-Indiana (OKI) Regional Planning Area. Computer tabulations providing area covered by each of 16 land-use categories were rapidly and economically produced for each of the OKI 225 watersheds and nine counties.

Summary of Recommendations

Preliminary considerations should be given to establishing data collection platforms (DCP) in Saginaw Bay to provide continuous monitoring of select water quality parameters.

CONTENTS

1. DISCUSSION OF PROGRAM AND RESULTS

This section reports on the work accomplished and results achieved during the first three months of a program to establish the cost benefits of LANDSAT for the surveillance and control of lake eutrophication. To accomplish this goal, LANDSAT data products are being generated to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments.

Dr. James Scherz, of the University of Wisconsin, is providing technical liaison support for lake studies in Wisconsin and is supporting the user agencies in that area. Similarly, Dr. V. Elliot Smith, of Cranbrook Institute of Science, is supporting the user agencies in Michigan and the Great Lakes.

These user agencies are providing, at no cost to NASA, user needs which include desired data formats, data timeline requirements (i.e., how fast data are needed and how long it maintains its value before update is needed), and data accuracy requirements (i.e., geometric and classification accuracy). These agencies are also providing detailed ground truth on water quality and watershed land use in conjunction with LANDSAT overflights and are participating in studies and evaluations to determine the usefulness and cost benefits of the LANDSAT data products.

The remainder of this section is subdivided to report on the work accomplishments and results achieved to support the on-going water quality programs of the three user agencies.

1.1 SUPPORT FOR THE EPA STUDY OF WATER QUALITY IN SAGINAW BAY

Coordination meetings were held with the EPA in order to review LANDSAT data requirements and to develop plans to provide the needed aircraft and LANDSAT support.

The EPA is sponsoring a 30-month study of water quality in Saginaw Bay. Important goals of this study are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the bays as a function of various control strategies.

To achieve these goals, the EPA will use LANDSAT data products produced by this investigation and surface/subsurface measurements obtained by the Cranbrook Institute of Science, under the direction of Dr. V. Elliot Smith (LANDSAT Co-Investigator). The surface measurement program has been underway since April of 1974. From each of 59 stations distributed over Saginaw Bay, some 30 water quality parameters are derived on an 18-day cycle that coincides with the LANDSAT overflights. On 1 April 1975, this measurement program was shifted from the LANDSAT-1 to the LANDSAT-2 schedule.

The first clear LANDSAT scene of the bay, coincident with surface measurements at the bay stations, was a 3 June 1974 scene. Techniques used in the computer processing of this scene and the results achieved are reported by Rogers (Appendix A) in the March 1975 Proceedings of the American Society of Photogrammetry. Of particular importance is the demonstration of a technique for editing LANDSAT measurements using the latitudes and longitudes of bay stations having known (measured) water quality parameters. At the time of this initial processing effort, the only parameter fully reduced for all bay stations which is a good indicator of turbidity was Secchi depth. Percent transmittance was available only for some stations, and total suspended solids were not yet measured. LANDSAT measurements from 22 bay stations were thus extracted and used to process the LANDSAT scene. This processing resulted in a geometrically-corrected color-coded image of Saginaw Bay showing nine discrete colors (categories) of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters.

Plans for the next reporting period include the continued measurement program in Saginaw Bay by Cranbrook Institute/EPA and support of a NASA overflight of the Bay in July or August of this year. The feasibility of mapping other water quality parameters over the bay will also be investigated. Linear regression techniques will be applied to evaluate correlations between the water quality parameters and between the water quality parameters and LANDSAT measurements. Those parameters showing the best correlation with LANDSAT measurements and having the greatest utility in the water quality model will be mapped over the bay.

1.2 SUPPORT FOR MICHIGAN'S SURVEY OF INLAND LAKES AND WATERSHEDS

Two coordination meetings were held with Mr. Howard D. Wandell of the Michigan Department of Natural Resources (DNR) Water Quality Appraisal (WQA) section. One meeting took place in Lansing, Michigan and the other took place at the Bendix facility in Ann Arbor, Michigan. DNR's LANDSAT data requirements were received during these meetings and plans were made to provide the needed aircraft and LANDSAT support. The DNR is committed, under the State Federal Water Pollution Control Act (Act 92-5000), to a state-wide survey of public lakes and their watersheds for the purpose of assessing the degree of

eutrophication in these lakes and the potential for further enrichment and pollution resulting from land-use development in the watershed. A requirement of the DNR program, as well as programs of other governmental agencies concerned with the maintenance and control of water quality, is to develop a knowledge of the interrelationships between the water quality parameters (turbidities, chlorophyll concentrations, etc.) and watershed land-use parameters (land-use categories and coverage).

To obtain the needed information, the Michigan DNR has selected test lakes whose watersheds contain various levels of urbanization. LANDSAT is to be used to inventory land use within these watersheds. The land-use data mapped by LANDSAT will be correlated with lake water quality measurements obtained by the DNR concurrent with the LANDSAT inventory. Possible correlations between LANDSAT measurements and water quality parameters will also be investigated.

LANDSAT's capability to provide the necessary watershed land-use inventory has been recently demonstrated in the Ohio-Kentucky-Indiana (OKI) Regional Planning Area. The techniques used and the results achieved are reported by Rogers in the Proceedings of the Symposium on Machine Processing of Remotely Sensed Data (Appendix B). Of particular importance is the technique for digitizing boundaries of watersheds from maps and extracting computer tabulations from these zones from the processed LANDSAT tapes. In the OKI area, the tabulations provided area covered by each of 16 land-use categories within each of 225 drainage areas. The 16 categories were also merged into ten categories and used to produce a color-coded map at a scale of 1 in. = 5,000 ft, with detail to 0.44 hectares for the 2,700 sq. mi. OKI region.

Plans for the next reporting period include a field measurement program by the Michigan DNR to obtain water quality parameters in test lakes concurrent with NASA aircraft and LANDSAT overflights. This mission is planned for July or August of this year. The LANDSAT scene corresponding to the mission will be processed, as in the OKI region, to tabulate land use with the watershed of the test lakes. The same LANDSAT tapes will be used to investigate correlations between LANDSAT measurement and DNR water quality measurements (parameters).

1.3 SUPPORT FOR WISCONSIN'S SURVEY OF INLAND LAKES

Professor James P. Scherz, LANDSAT Co-Investigator, visited Bendix on 28 and 29 March and on 6 May of 1975 for coordination meetings and to supervise preliminary processing of LANDSAT scenes of Wisconsin lakes. During the 6 May visit, Dr. Scherz briefed H. Wandell and the Michigan DNR Water Quality Agency on LANDSAT efforts in Wisconsin. A coordination meeting was also held between

Dr. Scherz and Mr. Pat Schraufnagel of the Wisconsin Department of Natural Resources (DNR) Bureau of Water Quality. During these meetings, the Wisconsin DNR's LANDSAT data requirements were reviewed and plans were made to provide the needed LANDSAT support.

One DNR goal is to develop a method of lake classification by trophic status, as required by Section 314 of the Federal Water Pollution Control Act Amendments of 1972. To achieve this goal, the Wisconsin DNR will evaluate the utility of LANDSAT data products produced by this investigation and the results of other investigations underway in Wisconsin.

Analysis of prior water resource records and data show that the period between mid-August and early September is the optimum window in which to acquire data for lake eutrophic classification. Thus, this LANDSAT effort is organized to obtain field and LANDSAT measurements during this period. To enhance the efficiency of these forthcoming field operations and to obtain a better understanding of LANDSAT's capability to categorize lakes, a number of LANDSAT scenes have been analyzed using the Bendix Multispectral-Data Analysis System (M-DAS) in Ann Arbor. The scenes included Madison Area (1756-16061, 18 August 1974), Spooner Area (1020-16255, 12 August 1972), and Ely Area (1020-16252, 12 August 1972). In all cases, Dr. Scherz had some corresponding field observations.

Preliminary results of these analyses show that lakes can be categorized by computer processing into clear, tannin, algal, and red clay lakes. These categories have significantly different spectral characteristics and are readily mapped by M-DAS. The LANDSAT measurements also indicate that tannin, algal, and red clay (silt) waters may be further subdivided (i.e., light, medium, heavy, etc). Lakes in which the bottom is visible in some LANDSAT band causes errors in categorization. Additional field work and study is needed to develop a procedure for handling bottom effects in lakes.

Plans for the next reporting period include flights over the Madison and Spooner area lakes between 1 and 20 August 1975 to assess algal types, weed types, weed extent, and eutrophic classifications. This flight also will serve as a planning flight for August photography and water sampling to be acquired by the University of Wisconsin and the Wisconsin DNR.

2. SIGNIFICANT RESULTS

LANDSAT CCTs were used as a basis to produce a geometrically-corrected color-coded image of turbidity and circulation patterns in Saginaw Bay (Appendix A). This imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. The categorized imagery was produced for approximately $0.50 per sq mi for the 1,143 sq mi bay. The categorized imagery provides an economical basis for extrapolating water quality parameters from point samples to unsampled areas. Furthermore, LANDSAT furnishes a synoptic view of water mass boundaries and circulation patterns that no amount of point sampling or monitoring can provide.

LANDSAT CCTs were used to inventory land use within 225 drainage areas and nine counties of the OKI regional area (Appendix B). Computer tabulations were produced to obtain the area covered by each of 16 land-use categories within each of the drainage areas and counties. The 16 categories were merged into ten categories and used to produce a color-coded map at a scale of 1 in. = 5,000 ft, wit detail to 0.44 hectares for the 2,700 sq mi region. The computer tabulations were produced for approximately $25.00 per drainage area or county. The ten-category color-coded map at 1 in. = 5,000 ft was produced for about $2.00 per sq mi. The entire project was completed within less than 90 days and at a cost of $20,000. It is not uncommon to find single counties spending this much to map the same categories with less detail over a smaller area.

3. PROBLEMS

No problems are impeding the program of this investigation.

4. RECOMMENDATIONS

It is recommended that NASA consider the deployment of some six to twelve fixed-bouyed data collection platforms (DCPs) to provide continuous monitoring of some water quality parameters in Saginaw Bay (i.e., turbidity, etc). A data terminal could possibly be established at the EPA lab at Grosse Ile, Michigan.

5. PUBLICATIONS

No papers were developed or released under this contract during this reporting period.

6. FUNDS EXPENDED

Total expenditures through May of 1975 are $6,924.

7. DATA USE

A tabulation showing the total value of the data allowed and received through 30 May 1975 follows.

Value of Data Allowed	Value of Data Ordered	Value of Data Received
$5,550	$0	$140

8. AIRCRAFT DATA

Aircraft data has not been received to date. A plan is being developed for one NASA flight for the July-August 1975 time-period.

APPENDIX A

COMPUTER MAPPING OF TURBIDITY AND CIRCULATION PATTERNS IN SAGINAW BAY, MICHIGAN (LAKE HURON) FROM LANDSAT DATA

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Computer Mapping of Turbidity and Circulation Patterns in Saginaw Bay, Michigan from LANDSAT Data		5. Report Date March 1975
		6. Performing Organization Code
7. Author(s) R.H. Rogers, L.E. Reed, V. Elliot Smith		8. Performing Organization Report No. BSR 4183
9. Performing Organization Name and Address Bendix Aerospace Systems Div. 3621 South State Rd Ann Arbor, Mich. 48107		10. Work Unit No.
		11. Contract or Grant No. NAS 5-20942
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Md. 20771		13. Type of Report and Period Covered Special Report
		14. Sponsoring Agency Code

15. Supplementary Notes

Published in Proceeding of the American Society of Photogrammetry 41st Annual Meeting; Washington, D.C.; March 1975.

16. Abstract

LANDSAT CCTs were used as a basis for producing geometrically-corrected color-coded imagery of turbidity and circulation patterns in Saginaw Bay, Michigan (Lake Huron). This imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. The categorized imagery provided an economical basis for extrapolating water quality parameters from point samples to unsampled areas. Furthermore, LANDSAT furnishes a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water Quality, Computer Mapping, ERTS, LANDSAT	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

COMPUTER MAPPING OF TURBIDITY AND CIRCULATION PATTERNS IN SAGINAW BAY, MICHIGAN (LAKE HURON) FROM ERTS DATA

Robert H. Rogers and Larry E. Reed
Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

V. Elliott Smith
Cranbrook Institute of Science
Bloomfield Hills, Michigan 48013

BIOGRAPHICAL SKETCHES

Dr. Robert H. Rogers is a senior staff engineer at Bendix, where he is a Principal Investigator for NASA/ERTS and Skylab/EREP programs. Rogers received his BS from Tri-State College, his MS from Southern Methodist University, and his PhD in EE from Michigan State University. He is a member of the ASP, and has published many papers in the field of Remote Sensing. Dr. V. Elliott Smith is Coordinator of Lake Research at Cranbrook Institute of Science, where he is the Principal Investigator for an EPA-funded survey of water chemistry in Saginaw Bay (Lake Huron). Smith received his BS and MS degrees in Biology from Florida State University and his PhD in Marine Biology from Scripps Institution of Oceanography. He has published several papers in the fields of biochemistry, biology, and remote sensing. Larry E. Reed is a projects investigator for Bendix and is actively involved in the processing and analysis of data from ERTS, Skylab, and Bendix multispectral scanners. He has seven years of experience as an Air Force image interpreter, using aerial photography, side-looking radar, and infrared imagery.

ABSTRACT

Computer techniques developed for mapping water quality parameters from ERTS data are demonstrated, using ground truth collected in an ongoing survey of water quality in Saginaw Bay, Michigan (Lake Huron) sponsored by the U.S. Environmental Protection Agency. Chemical and biological data were collected in concert with ERTS passes at 59 bay stations within the 2,960 square kilometer (1,143 square mile) test area. These ground truth measurements include water turbidity and clarity, chlorophyll, algal populations, total and dissolved nutrients, and metals.

A technique for transforming Earth coordinates (latitude and longitude) of bay stations to ERTS tape coordinates (scan line and element number) was developed and applied to edit ERTS measurements near stations representative of a known water quality parameter. These spectral samples were used by the computer to produce geometrically-corrected color-coded imagery and maps of turbidity of the entire bay. These maps show nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters.

These maps and data, rapidly produced from ERTS data, provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas. Furthermore, ERTS furnishes a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide.

BACKGROUND

Recent investigations have studied the feasibility of using ERTS-1 to detect and monitor water quality parameters (Refs. 1, 2, 3, 4)* and the effects of land use on these parameters (Ref. 5). Results of these efforts show that ERTS is capable of detecting subtle changes in water color and reflectivity where the concentration of suspended particles (causing backscatter) is at least a few milligrams per liter. At lower values of turbidity, atmospheric and sensor "noise" interferes substantially. It has also been observed in many ERTS images that the distribution of turbidity within small inland lakes is fairly uniform (Ref. 1), whereas in large lakes and bays it is highly variable (Refs. 2, 3). This investigation recognizes the growing need to map turbidity and color patterns in the Great Lakes, inasmuch as they represent discrete water masses, circulation trends and zones of differing productivity, and water quality. ERTS monitoring, as an adjunct to conventional point-sampling should also provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provide a synoptic view of water mass boundaries.

Several institutions and federal agencies in the United States and Canada are conducting a comprehensive survey of water quality and circulation in Lakes Huron and Superior, the Upper Lakes Reference Study, (a part of the United States/Canadian Great Lakes Water Quality Agreement of 1972). One such agency is the U.S. Environmental Protection Agency (EPA). In Saginaw Bay (Lake Huron), EPA is sponsoring a 30-month modeling study of water quality. This bay is heavily enriched by drainage from more than 16,060 square kilometers (6,200 square miles) of urban and agricultural land. EPA's program will develop a deterministic model which will describe water quality changes within the bay and their relationship to enrichment and pollution caused by man. The increasing eutrophication of Saginaw Bay has an impact on both the American and Canadian waters of Lake Huron, Lake Erie, and Lake Ontario. The resulting model will be used to evaluate various strategies to control nutrient flow into the bay. Important goals in this project are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay, to monitor inputs of nutrients from its watershed, and to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

---

*References, tables, and illustrations can be found, in that order, at the end of this paper.

Since April of 1974, Saginaw Bay has been monitored by EPA at 59 stations distributed over its 2,265 square kilometer (1,100 square mile) area. At each station and depth, some 30 parameters are measured in the field or laboratory. While most of these chemical, biological, and physical factors are not directly detectible by any remote sensor, they all influence the productivity and, therefore, the color and reflectance of bay waters.

In response to EPA requirements for large area surveillance of water quality and watershed land use, NASA's ERTS-B investigation (ID 23250) is using the Saginaw Bay area to demonstrate the cost benefits of ERTS for mapping the needed parameters. One goal of this investigation is to determine which water quality parameters can best correlate with ERTS measurements. This paper reports on preliminary results directed toward this ERTS-B goal.

TEST SITE

Saginaw Bay, as shown on the map of Michigan in Figure 1 and in the ERTS image of Figure 2, is a shallow extension of Lake Huron, bounded by five counties of southeastern Michigan. The bay has an area of some 2,960 square kilometers (1,143 square miles) and a maximum length and width of 82 kilometers (51 miles) and 42 kilometers (26 miles), respectively. Mean depth of the inner bay is 4.6 m (15 ft) and of the outer bay, 14.6 m (48 ft). The Saginaw River enters the bay at its extreme southwestern end. This river and its tributaries drain a watershed of more than 16,060 square kilometers (6,200 square miles), which contains four major cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and aesthetic values have been the result of eutrophication. The natural movement of pollutants from the bay into southern Lake Huron helps to reduce water quality throughout the lower Great Lakes as well. While circulation within the bay is highly wind-dependent, the pattern is generally counterclockwise. Clear Lake Huron water enters mainly along the western shore; turbid bay water exits along the eastern shore. Significant but unknown quantities of sediment are resuspended regularly by wave action. The lower two-thirds of Saginaw Bay usually freezes over during January and February. These and other characteristics of Saginaw Bay are well documented (Ref. 6) by previous studies.

GROUND TRUTH PROGRAM

The EPA measurement program in Saginaw Bay is obtaining a base of information on water quality which will be used to develop and test models of circulation, nutrient loadings, and algal productivity. Since April 1974, surface and subsurface measurements have been obtained at the 59 bay stations shown in Figure 3, on an 18-day interval to coincide with the ERTS overflights.

The first clear ERTS scene of the bay, coincident with surface measurements at the bay stations, was the 3 June 1974 scene noted previously in Figures 1 and 2. The corresponding cruise tracks of the survey vessels obtaining measurements at the bay stations are shown in Figure 3. Typically, as in this 3 June mission, the western half of the bay, containing 31 stations, is sampled on the same day as the ERTS overflight. The remaining 28 stations are sampled on the following two days. ERTS measurements edited near 22 of the bay stations monitored on the day (i. e., coincident with ERTS overflight) were used in the processing reported in this paper.

Field measurements at each of the bay stations include temperature, pH, dissolved oxygen,conductivity, alkalinity, and turbidity. Turbidity is indicated by Secchi depth and percent transmittance measurements. Variables measured in the laboratory include soluble nutrients (nitrate-nitrite, orthophosphate, sulfate, silicate, and ammonia), organic materials (nitrogen, phosphorus, carbon, and chlorophylls), chloride and metals (sodium, potassium, calcium, magnesium, and six trace metals), and total suspended solids. Enumerations of phytoplankton and zooplankton are also made. Coordinated studies of current patterns, nutrient inputs, and bottom fauna are also underway by EPA.

COMPUTER PROCESSING OF ERTS DATA

The need for faster and more economical mapping of water quality and land use has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target categorization and mapping. These categorization techniques (Refs. 7, 8) have been under continued development at Bendix for the past eight to ten years, primarily using aircraft multispectral scanner data and, more recently, using ERTS/MSS and Skylab/EREP-S192 data.

The elements of the Bendix data center used to process data for this study include Digital Equipment Corporation 1.5-M-word disk packs, two nine-track 800-bit-per-inch tape transports, a line printer, a card reader, and a teletype unit. Other units are a color moving-window computer-refreshed display, a glow-modulator film recorder, and a Bendix Datagrid® System 100 for digitizing graphical data. Figure 4 illustrates the major steps used in transforming the 3 June ERTS CCTs into turbidity maps and data on Saginaw Bay. The steps used and results achieved are briefly summarized in the following paragraphs.

One of the processing steps is to establish the water categories that can be feasibly mapped from ERTS data with an acceptable categorization accuracy. This step requires locating and designating to the computer a number of ERTS picture elements or "pixels" that best represent the water categories of interest, the "training areas". It is these training area measurements that are used by the computer to interpret ERTS measurements over the entire scene.

The first processing goal was to generate a turbidity map of the bay. Hence, the first processing requirement is to locate and extract ERTS measurement (training areas) representative of various degrees of turbidity. At the time of preparation of this paper, the only parameter fully reduced for all bay stations, which is a good indicator of turbidity, is Secchi depth. Percent transmittance was available only for some stations and total suspended solids were not yet measured.

To obtain training measurements representative of various categories of turbidity as measured by Secchi depth, a procedure was developed for transforming the bay station coordinates from latitude and longitude units to ERTS tape scan line and element numbers.

Earth to ERTS Coordinate Transformation

There are three basic steps involved in the automatic referencing of ground coordinates of bay stations to ERTS coordinates. The first step consists of automatic retrieval of the latitude and longitude of carefully selected ground control points from a map through a digitizing process. The criteria for selecting these ground control points is they can be easily and accurately identified on ERTS imagery. The second step consists of converting the latitude and longitude of these ground control points to ERTS coordinates, using a theoretical transformation derived from known and assumed spacecraft parameters such as heading, scan rate, and altitude, and from a knowledge of Earth rotation parameters. The ERTS coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. The approximately-derived ERTS coordinates and transformation are used, however, to identify the actual ERTS coordinates associated with the ground control points. To accomplish this, the coordinates of a ground control point is input to the Bendix data processing system. The approximate transformation computes the ERTS coordinates and displays the area on a TV monitor. Positional error of the ground control points displayed to the operator are designated to the computer by cursor. This error measurement is used by the computer to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional ground control points until the desired geometric accuracy is achieved. This rapid interactive procedure is essential for producing a transformation matrix which provides an accurate transformation of Earth to ERTS coordinates.

Analysis Phase

When assured that the Earth-to-ERTS coordinate transformation was correct and the bay station areas were being accurately displayed on the TV monitor, the coordinates of training areas about the bay stations representative of nine Secchi depths were designated to the computer. This was accomplished by placing a rectangular cursor over the desired bay station area and assigning a training area designation, category code, and color code. Several bay station areas were picked for each category, as shown by Table 1. The color code was used in

later playback of the tapes when the computer-categorized data was displayed in the designated colors.

The ERTS spectral measurements within the training area boundaries were edited by the computer from the computer-compatible tape (CCT) and were processed to obtain a numerical description representing the "spectral characteristics" (computer processing coefficients) of each water category. One of these numerical descriptors is the average signal in each ERTS band when viewing a water mass of a specified Secchi depth, as shown in Table 1. To test the computer's capability to use these spectral characteristics, they were first applied to categorize data from known bay station areas. The processed results were viewed on the TV monitor and output in the form of accuracy tables.

When satisfaction with the categorization accuracy was achieved on the water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the CCT covering the area. This first step in the categorization processing resulted in new or categorized CCTs, in which each ERTS pixel is represented by a code designating the interpreted water categories. This tape was used to generate geometrically-corrected color-coded images at 1:1,000,000 scale. Enlargements were produced to obtain 1:250,000 scale images. In this categorized imagery, color represents the computer's interpretations, based on the training measurements, as to turbidity as indicated by Secchi depth. The turbidity map of Saginaw Bay, shown in Figure 5, was produced from this color-categorized imagery.

RESULTS AND ANALYSIS

ERTS spectral measurements edited from bay stations of Secchi depth from 0.6 to 3.3 meters show a linear relationship; for depths less than 0.6 meters, a nonlinearity (jump in measurements) is apparent.

To establish categorization accuracy based on Secchi depth, ERTS measurements within a 100-pixel box centered on each bay station was categorized and results were noted and plotted in Figure 6. Secchi depth measurements obtained by boat at the bay stations and measurements categorized by ERTS are noted in the figure. The values are arranged in order of increasing Secchi depth and are grouped by day of measurement. From the data, it is evident that the correspondence of measured and predicted Secchi depths is best on 3 June, the day of ERTS coverage. For a few stations (36, 34, 39, 44, 38, 43), there is a wide discrepancy between measured and predicted Secchi depth, particularly on 4 and 5 June. Notably, all of these stations are located either in areas of partially unclassified water, along boundaries between category-areas, or both. Possible shifts in water masses during the day or two between ERTS passage and Secchi depth measurement could account for this difference.

Conversely, predicted values at stations located well within category-areas are more reliable, even on 4 and 5 June.

There are several factors that could affect the accuracy of Secchi depth predictions from ERTS data. Some of these include:

a. Secchi depth measurement. To some degree, Secchi depth measurement is affected by the observer's eyesight, the time of day, the weather, the state of the sea, and other factors. As turbidity increases, small errors of measurement become more important, particularly for Secchi depths less than 1 m.

b. Variation of reflectance. For reasons of varying particle size and color, surface conditions, sun angle, etc., Secchi depth may not vary linearly with the volume of back-scattered light, as recorded by ERTS.

c. Atmospheric interferences. Non-uniform attenuation of the signal by atmospheric dust, haze, etc. further complicates the relationship between Secchi depth and ERTS measurements.

d. Location of stations by ground crews. Navigational errors can lead to faulty comparison of measured and predicted values, especially for stations located along water mass boundaries. Depending on the location and conditions, the accuracy of ship positioning may vary by several hundred meters.

Study of the turbidity map, Figure 5, produced from the categorized ERTS imagery has confirmed some known features of circulation and water quality in Saginaw Bay. Previous surveys of the bay (Ref. 6) have indicated that the predominant flow of Saginaw River water is northward along the eastern shore of the bay. Less turbid Lake Huron water dominates the outer bay and enters the inner bay chiefly along the western shore. Zones of mixing and local circulation are apparent on the map, as are shoal areas where sediments evidently have been resuspended. Clearly, the image categories mapped from ERTS are related to turbidity levels.

Results of the categorization based on Secchi depth also show that Saginaw River water is a distinct category that is traceable outside the river mouth as it blends with less turbid bay water (forming a new category) and moves up the eastern shore. The Sebewaing River plume is shown as "unclassified" water. Also, good distinction is made between outer and central inner bay water, the latter being more turbid. Finally, the scene categorized from ERTS portrays very distinct boundaries between water masses and little mixing of categories representing widely different turbidities.

CONCLUSIONS

Turbidity maps and data can be rapidly produced from ERTS tapes, using point sampling at the surface in a few select locations. Further work will establish other water quality parameters than can be mapped by ERTS and the number of sampling stations needed.

Only a few water quality parameters; namely, turbidity, chlorophylls, algal populations, and particulate carbon;are expected to have a strong influence on the color or reflectivity of Saginaw Bay water. However, generated maps showing these parameters may provide the tracer needed to map other water quality factors. For instance, highly polluted water from the Saginaw River is characterized not only by its extreme turbidity, but by high chloride and conductivity values as well. Therefore, under some conditions, it should be possible to map chloride content and conductivity along with turbidity. This possibility will also be examined in future work.

REFERENCES

1. R. Rogers and V. Smith, "Utilization of ERTS-1 Data to Monitor and Classify Eutrophication of Inland Lakes," NASA Contract NAS 521810, Final Report, Bendix BSR 4168, November 1974.

2. V. Klemas, M. Otley, W. Philpot, C. Wethe, and R. Rogers, "Correlation of Coastal Water Turbidity and Current Circulation with ERTS-1 and Skylab Imagery," Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 1974.

3. A. E. Coker, A. Higer, and C. Goodwin, "Detection of Turbidity Dynamics in Tampa Bay, Florida, Using Multispectral Imagery from ERTS-1," NASA Symposium on Significant Results Obtained from the ERTS-1, Washington, D. C., March 1973.

4. J. Scherz, S. Klooster, and J. VanDomelen, "Aerial and Satellite Photography – A Valuable Tool for Water Quality Investigations," Proceedings ASP-ACSM 1973 Fall Convention, Walt Disney World, Orlando, Florida, 2-5 October 1973.

5. R. Rogers, L. Reed, N. Shah, and V. Smith, "Automatic Classification of Eutrophication of Inland Lakes from Spacecraft Data," Proceedings Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 1974.

6. P. L. Freedman, "Saginaw Bay; An Evaluation of Existing and Historical Conditions," EPA Report 905/9-74-003, April 1974.

7. R. Dye, "Multivariate Categorical Analysis," Bendix Aerospace Systems Division Special Report BSR 4149, June 1974.

8. R. Dye, P. Hanson, and C. Crawford, "Signature Data Processing Study," Bendix Report BSR 2949, NASA 9-9848, August 1970.

Table 1 ERTS Spectral Measurements from Bay Stations of Known Secchi Depth Used to Generate a Nine-Category Secchi Depth Map of Saginaw Bay.

Bay Stations Used to Obtain ERTS Measurements Representative of Secchi Values	Secchi Depth Bay Stations (Meters)	ERTS Measurements (Average Digital Counts) Edited from Areas of Known Secchi Depth			
		Band 4	Band 5	Band 6	Band 7
1, 9, 54, and 55	0.3	52.5	40.2	27.7	11.4
5 and 7	0.6	43.4	26.7	15.8	3.9
14 and 59	0.8	45.8	28.4	15.7	3.7
2	1.0	47.0	27.2	14.5	3.3
15, 18, and 37	1.3	47.6	26.5	13.4	3.2
20	1.5	45.4	23.5	12.3	2.4
19, 23, 28, 29, and 36	1.7 to 1.8	44.3	23.8	11.9	2.5
31 and 35	2.2	44.4	23.2	12.7	3.2
40 and 45	3.0 to 3.3	42.3	19.7	12.0	3.0

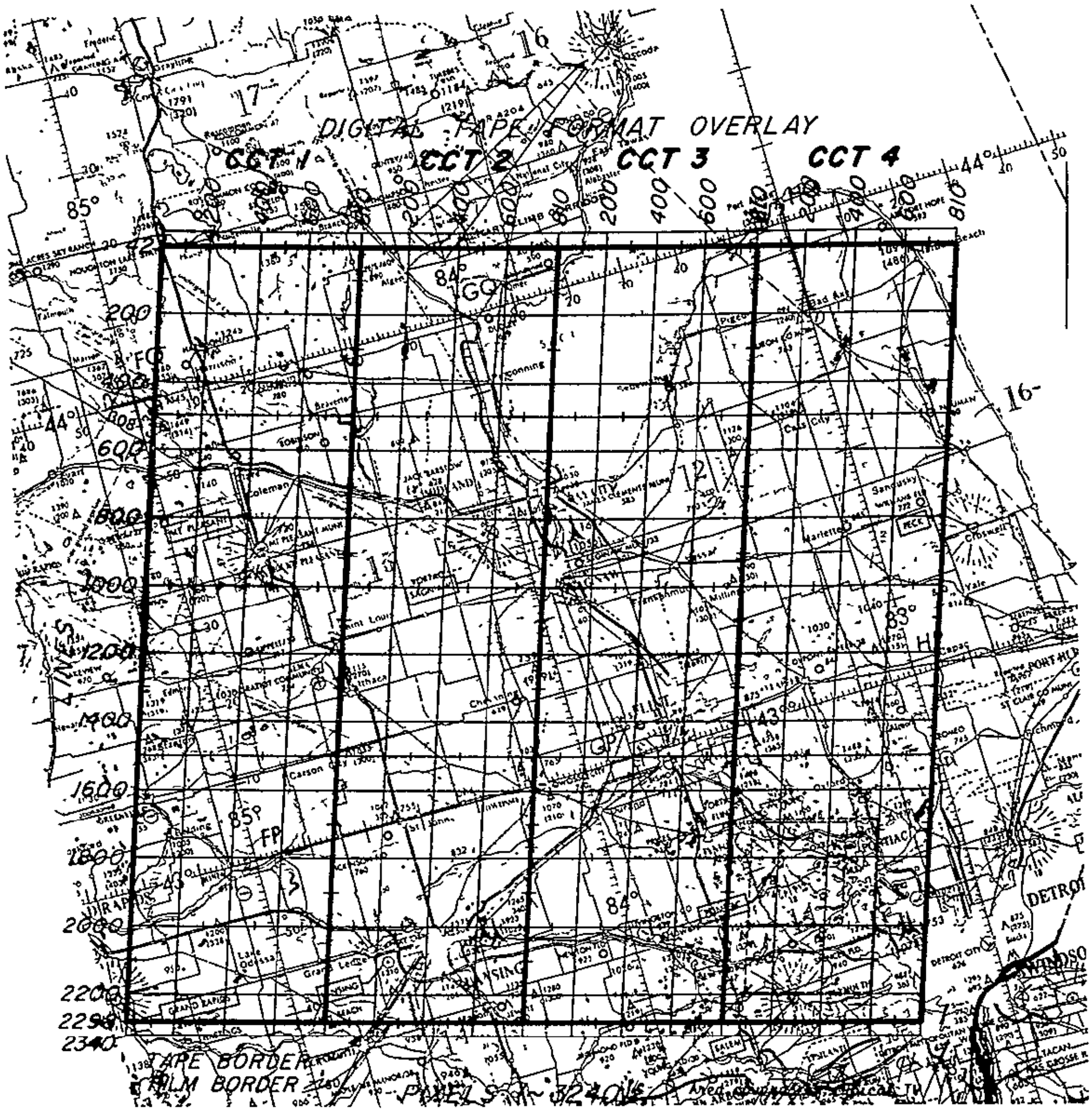


Figure 1 Map of Michigan at 1:1,000,000 Scale Showing Saginaw Bay Test Site and Coverage of ERTS Image Shown in Figure 2. The ERTS coverage diagram illustrates the manner in which ERTS image data is subdivided into four Computer Compatible Tapes (CCTs).

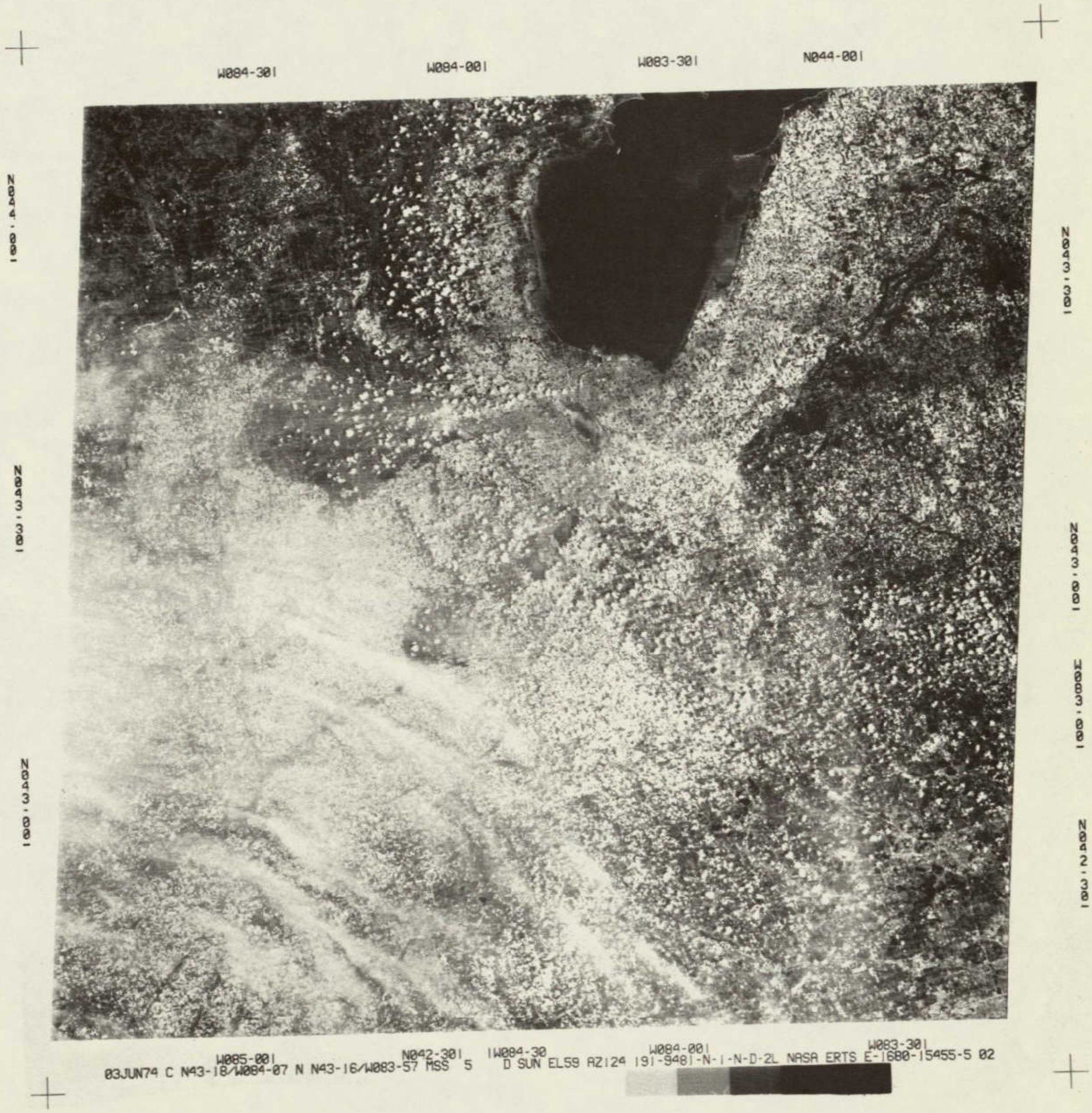


Figure 2 ERTS Image (1680-15455, Band 4) of Lower Saginaw Bay Area for June 3, 1974. Figure 1 shows a 1:1,000,000 scale map of Michigan and area covered by this scene.

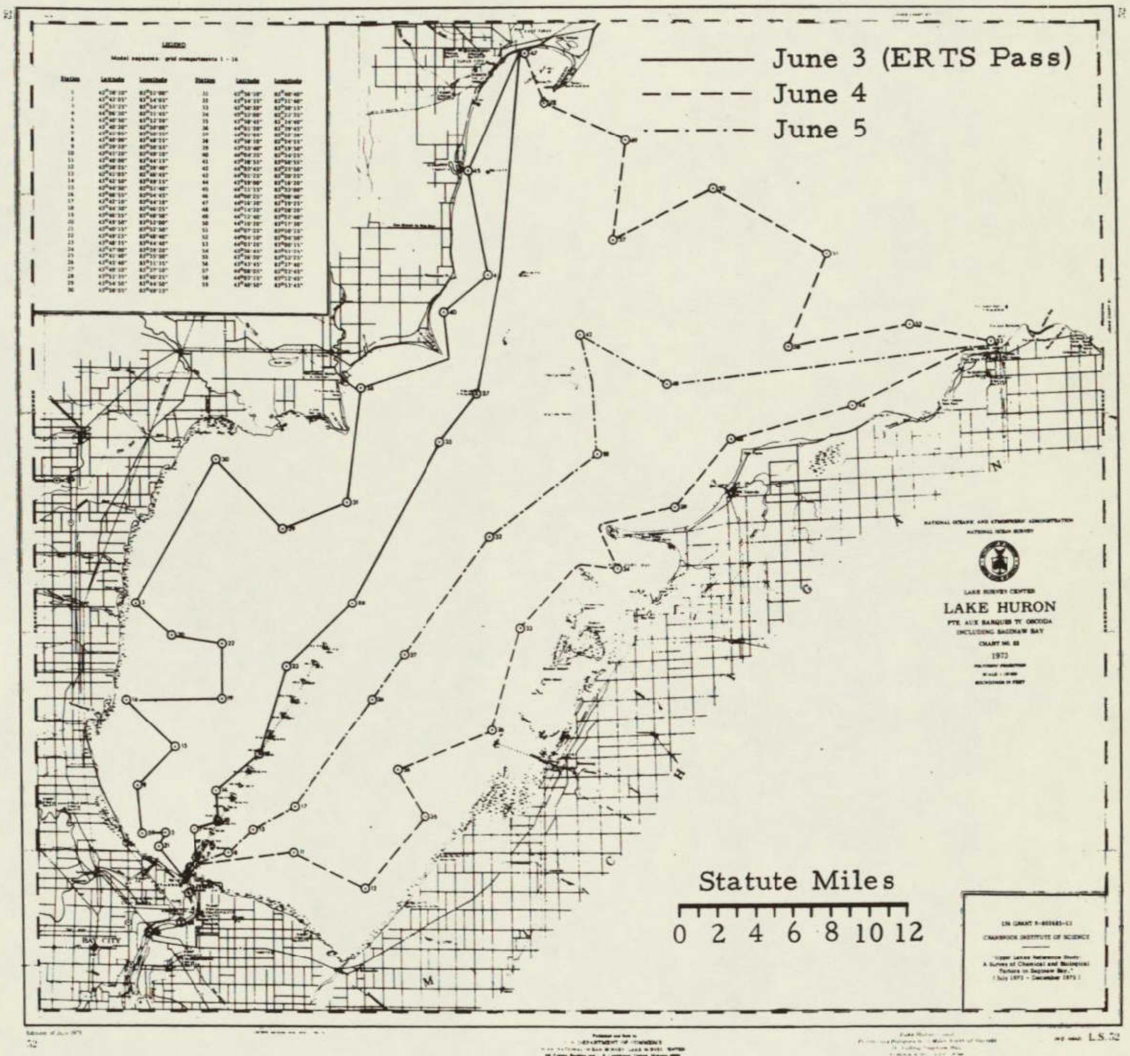


Figure 3 Map of Saginaw Bay with Location of the 59 Bay Stations Denoted by ⊙ , Also Shown are Cruise Tracks of Two Survey Vessels on Saginaw Bay, June 3-5, 1974. Ground truth was collected at 31 stations during a 9 hour period on the day of ERTS passage (June 3).

ORIGINAL PAGE IS
OF POOR QUALITY

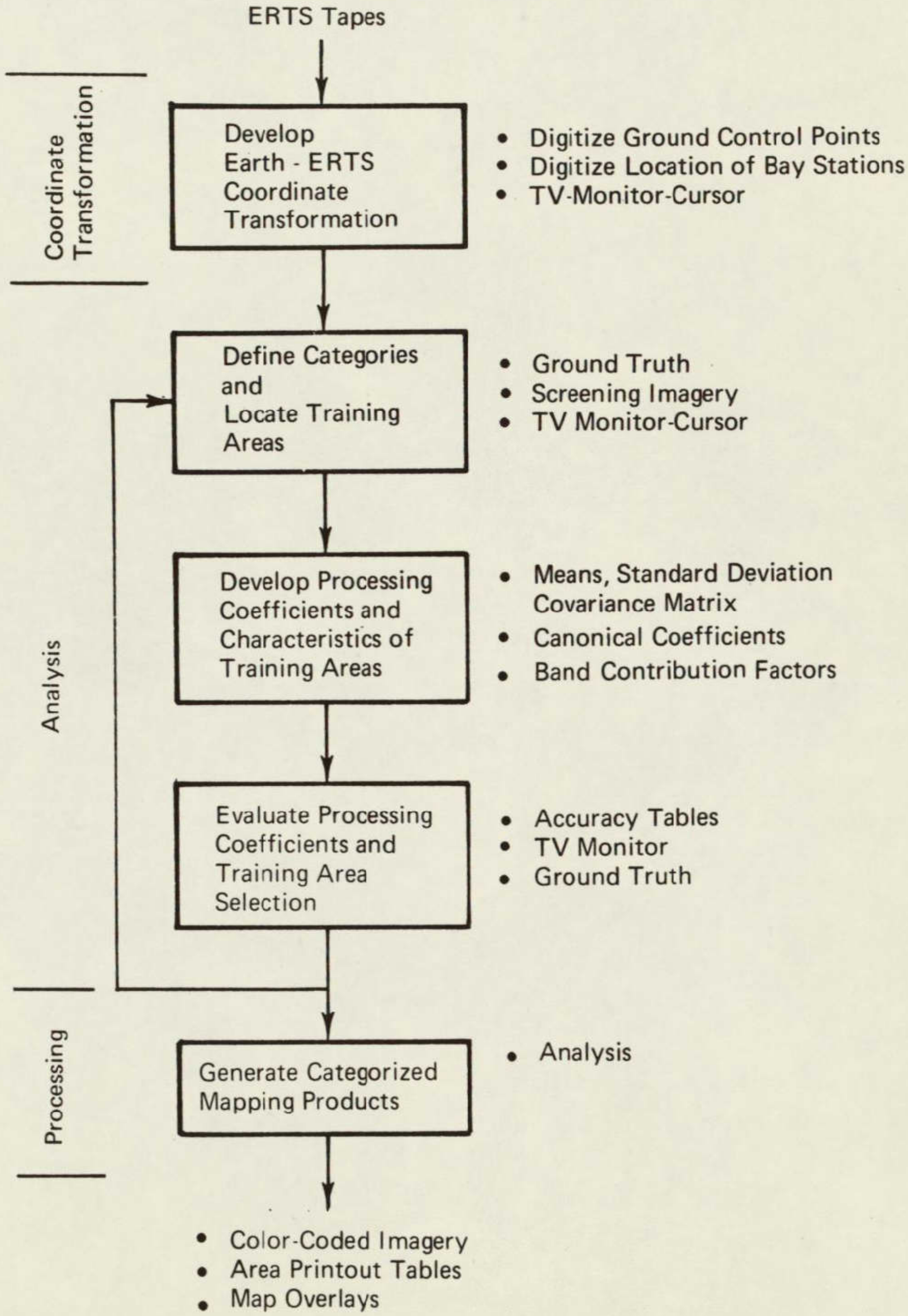


Figure 4 Flow Diagram for Processing and Analysis of ERTS Computer Compatible Tapes

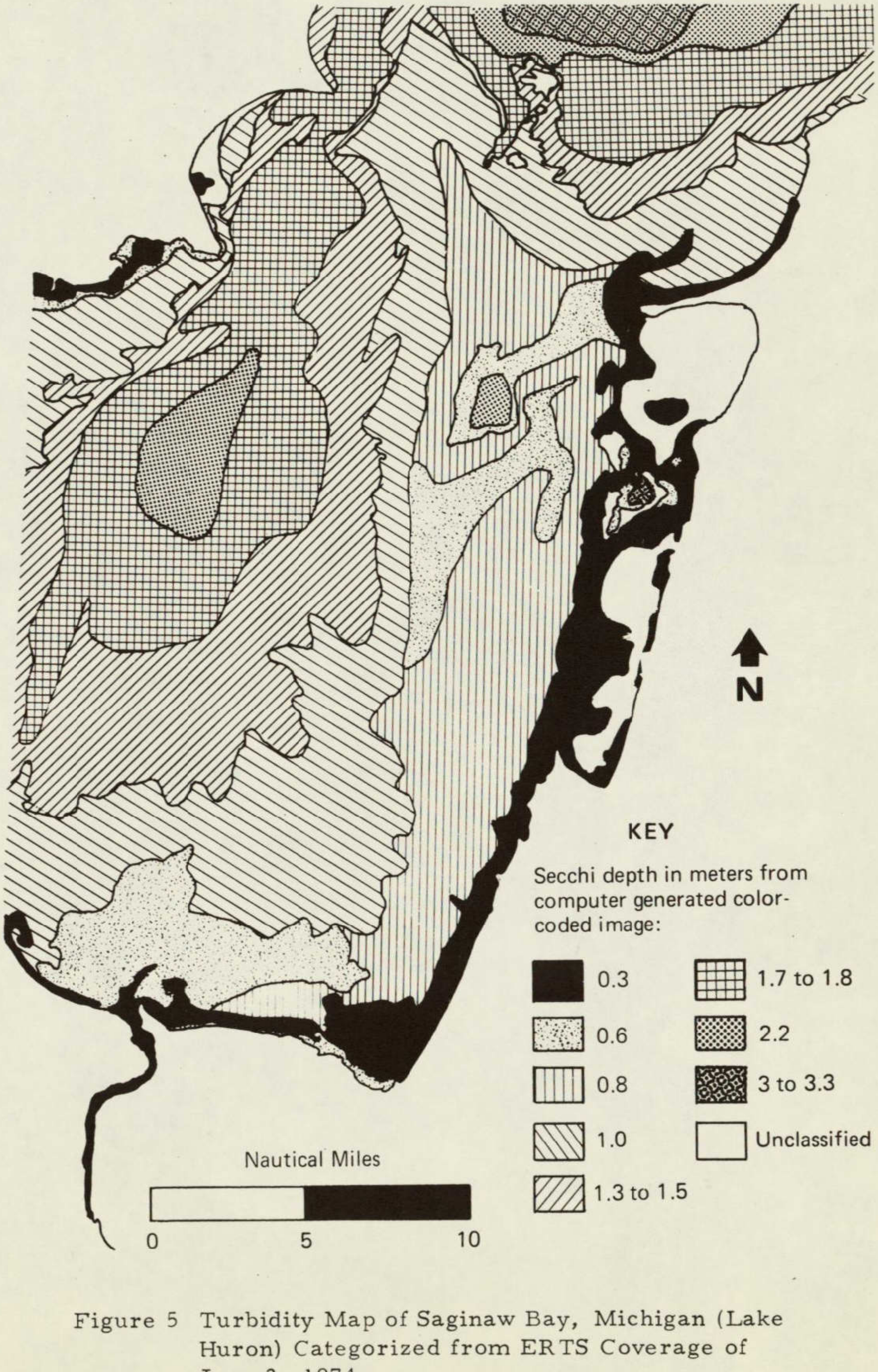
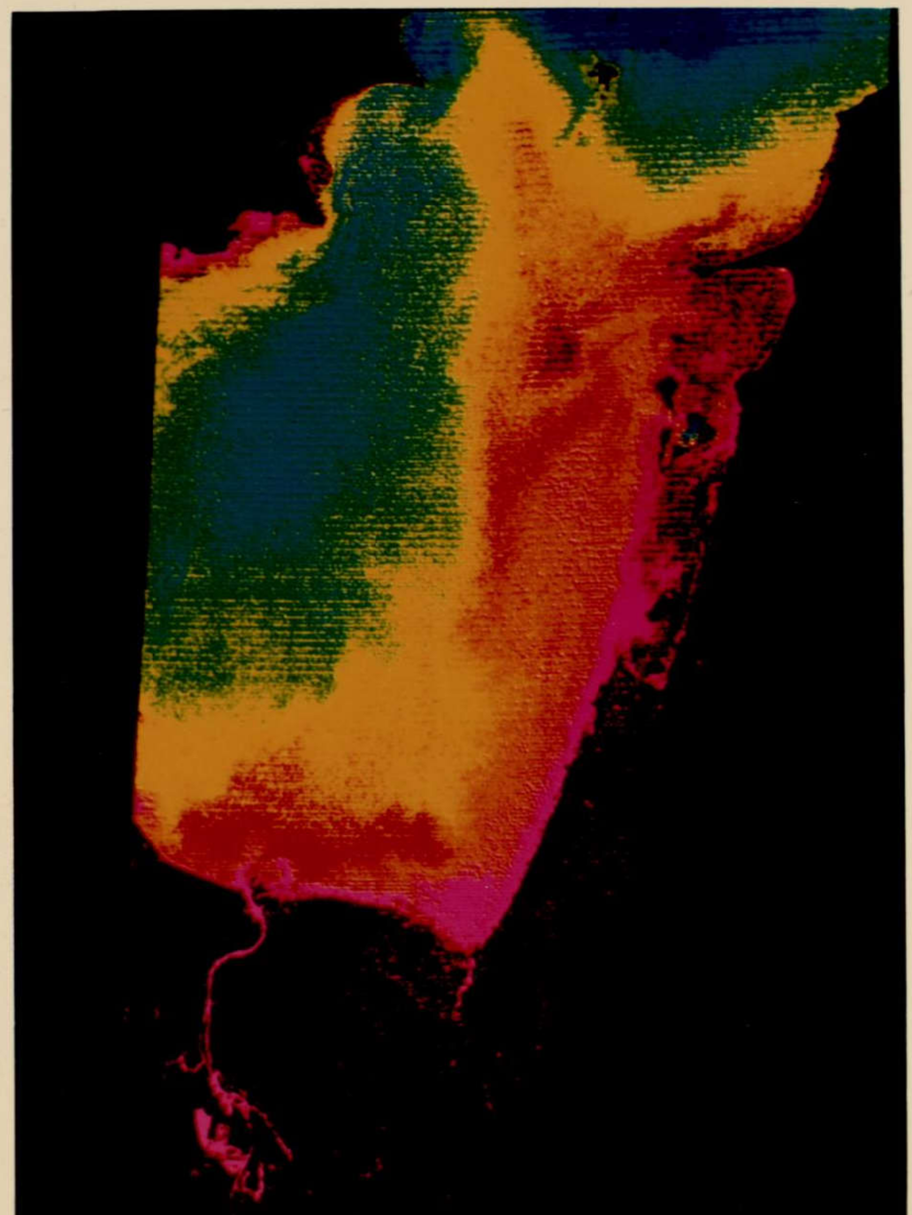


Figure 5 Turbidity Map of Saginaw Bay, Michigan (Lake Huron) Categorized from ERTS Coverage of June 3, 1974.

TURBIDITY MAP OF SAGINAW BAY

ERTS Scene 1680-15455
June 3, 1974



Color	Secchi Depth (meters)
Magenta	0.3
Red	0.6
Orange	0.8
Yellow	1.0
Dark Green	1.3
Light Green	1.5
Blue Green	1.7 to 1.8
Cyan	2.2
Dark Blue	3 to 3.3
Black	Uncategorized

Map covers area approximately 25 by 40 nautical miles.

ORIGINAL PAGE IS OF POOR QUALITY

Produced by Computer processing of ERTS tapes by Bendix Aerospace Systems Division.

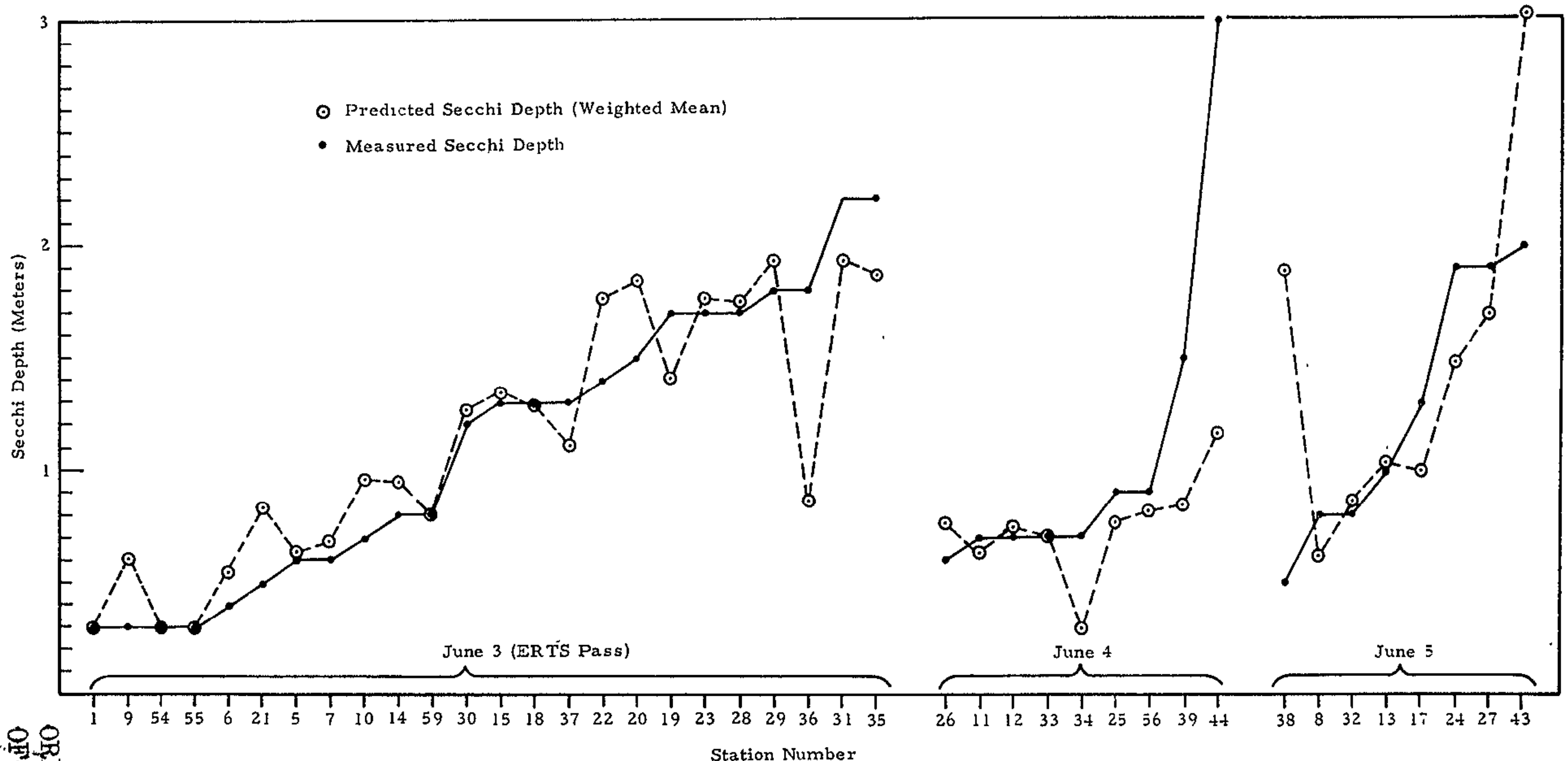


Figure 6 Comparison of Measured and Predicted Secchi Depths.

APPENDIX B

ENVIRONMENTAL MONITORING FROM SPACECRAFT DATA

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Environmental Monitoring from Spacecraft Data		5. Report Date June 1975
		6. Performing Organization Code
7. Author(s) R.H. Rogers, et. al		8. Performing Organization Report No. BSR 4183
9. Performing Organization Name and Address Bendix Aerospace Systems Div. 3621 South State Rd. Ann Arbor, Mich. 48107		10. Work Unit No.
		11. Contract or Grant No. NAS 5-20942
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Md. 20771		13. Type of Report and Period Covered Special Report
		14. Sponsoring Agency Code

15. Supplementary Notes

Published in proceedings of Symposium on Machine Processing of Remotely Sensed Data; Purdue University; June 1975.

16. Abstract

LANDSAT CCTs were used as a basis for inventorying land use within each of the Ohio-Kentucky-Indiana Regional Commissions, 225 drainage areas, and nine counties. Computer tabulations were produced to obtain the area covered by each of 16 land-use categories within 225 drainage areas. The 16 categories were merged into ten categories and mapped at a scale of 1 in. = 5,000 ft, with detail to 0.44 hectares for the 2,700 sq. mi. region. These products were produced in less than 90 days, at a cost of $20,000. It is not uncommon to find single counties spending this much to map similar categories within a much smaller area.

17. Key Words (Selected by Author(s)) Water Quality, ERTS, Computer Processing, Land Use.	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
		10	

ENVIRONMENTAL MONITORING FROM SPACECRAFT DATA

R. H. Rogers*, C. L. Wilson*, L. E. Reed*, N. J. Shah*, R. Akeley*, T. G. Mara**, V. Elliott Smith***

*Bendix Aerospace Systems Division, Ann Arbor, Michigan;
**Ohio-Kentucky-Indiana Regional Council of Governments, Cincinnati, Ohio;
***Cranbrook Institute of Science, Bloomfield Hills, Michigan

ABSTRACT

Section 208 of the Federal Water Pollution Control Act Amendments of 1972 provided the opportunity and funding to fight water pollution through the use of regional water quality planning. A common requirement of the 208 program is to develop a capability of predicting water quality in the rivers and lakes resulting from existing and potential land-use policies. To achieve this capability, the Ohio-Kentucky-Indiana (OKI) Regional Council of Governments is developing a deterministic model capable of predicting sediment and nutrient flow into the waterways. An essential input to OKI's model is an accurate map of land use within the watersheds. This information was obtained by OKI through the machine processing of LANDSAT-1 digital tapes. Computer tabulations were generated to obtain area covered by each of 16 land-use categories within 225 drainage areas. The 16 categories were merged into 10 categories and mapped at a scale of 1 inch = 5,000 feet with detail to 0.44 hectares (1.1 acres) for the 2,700-square mile region. The map products and data were produced within a period of less than 90 days at a cost of $20,000, a significant improvement in dollars and time over conventional mapping techniques.

BACKGROUND

State and federal agencies are becoming increasingly alarmed over the loss in water quality in many of our public lakes and rivers. Much of this loss is a direct result of pollution generated by man and the increased sediment and nutrient runoffs into the rivers and lakes resulting from urbanization in the watersheds. It is now realized that our water resources are not inexhaustible and that land development in the watersheds must be planned if the conflict between utilization of our water resources and maintenance of the quality of our lives is to be resolved.

To provide for this needed planning, the Federal Water Pollution Control Act Amendments of 1972 created several programs to fight water pollution. Under provisions of Section 208 of that act (EPA, 1974), regional councils of government such as OKI were given the opportunity and the funding to undertake regional water quality planning. The new 208 program (OKI 1974) differs from past HUD-financed water and sewer planning in that this new EPA-administered program deals with all sources of pollution, not just pollution fro[illegible] municipal sewerage systems. Other sources of pollution for which planning responsibility is given are industrial discharges and what are termed "non-point" sources. These non-point sources include sedimentation and runoff of pesticides and fertilizers from agricultural areas, urban runoff, erosion from construction sites, and leachates from septic tanks.

A common requirement of the 208 programs and programs of other governmental agencies concerned with the maintenance and control of water quality is the development of a knowledge of the interrelationships between the water quality parameters (turbidity, chlorophyll concentrations, etc.) and land-use parameters (land-use categories and coverage, etc.).

To obtain this information, OKI is developing a deterministic model capable of predicting water quality in rivers and lakes resulting from existing and potential land-use policies. The inventory of present land use together with population projections will provide OKI a basis for developing future land-use maps. Given a future land use, the water quality model will be used to predict the imlact of future development on water quality. This analysis will aid OKI in identifying critical areas where alternatives will have to be developed to minimize any deleterious impact on water quality. This may involve redirecting growth to other areas where the impact might not be so severe, or changing the character of the growth to minimize any harmful impact on water quality. The water quality plan will, in effect, contain a significant land-use planning element. The 208 water quality planning program, in fact, may provide the most rational basis for land-use planning available to date.

Accurate water and land-use parameters are essential in the development and application of the water quality model.

While many factors influence water quality, a dominating one is the use of land adjacent to and surrounding the lakes and rivers, the "drainage areas." During periods of rain or thaw, this area discharges sediment and nutrients directly to the water bodies by means of surface runoff or storm drainage. Each land-use category has its own special characteristic (EPA-1430, 1973) which is important in the calculation of the quantity and quality of storm-water runoff. For example, fertilized lawns (tended grass) and paved streets discharge more nutrients, especially phosphorus, than do rangeland (untended grass) and forested land. Cropland is often tilled in the spring when rainfall is heaviest and absorbs much of the water, but erosion in the form of sediments, which includes pesticides and fertilizer, are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt from streets and buildings.

To establish sediment and nutrient flows from the drainage areas into the waterways, accurate information on drainage area land use is essential. Land-use information presently available to planning agencies is not adequate for water quality planning purposes. In almost every case, agricultural and vacant land has been lumped into one category such as miscellaneous. Urban land uses often are not identified (categorized) in terms usable for water quality planning. Also, most 208 program planning areas are extremely large. The OKI Region covers 7,024 sq km (2,712 sq mi) and contains 225 drainage areas. For these reasons, OKI decided that the traditional techniques for land-use inventory - field inspection and interpretation of aerial photographs - are impractical in that they are too costly in terms of dollars and time. In its quest to evaluate new sources and techniques for obtaining the needed land-use information, OKI established and accomplished the following two goals:

- Produced a 10-category land-use map of the OKI regional area showing: rangeland, fallow cropland, water, cropland, two categories of forest land, core city/industrial, inner city, urban, and suburban. The smallest detail mapped was 0.44 hectare (1.1 acres) and the map scale was 1 in. = 5,000 ft.
- Produced computer tabulation of area covered by 16 land-use categories within 225 drainage areas and nine counties.

OKI achieved its mapping goals within a period of 90 days at a cost of only $20,000, a significant improvement over conventional techniques.

OKI REGION

The OKI objectives were achieved through the machine processing of the 14 April 1973 LANDSAT-1 scene shown in Figure 1. The OKI region shown in this scene consists of the Ohio Counties of Hamilton, Clermont, Butler, and Warren; the Indiana Counties of Dearborn and Ohio; and the Kentucky Counties of Boone, Kenton, and Campbell. This 2,712-sq mi region centered around Cincinnati is expected to increase its population to over 2,000,000 by the year 2000, a 35% growth from its present figure of about 1,600,000. The area is characterized by its many low hills and dense forest cover. The Ohio River and its tributaries drain the OKI region. The Ohio, Great Miami, and Little Miami rivers can also be seen in the LANDSAT image of the region. All of the rivers and lakes in the region are highly valued for recreational and residential uses. Increasingly heavy public use makes it vital that water quality consideration remains as one of OKI's highest planning priorities.

MACHINE PROCESSING OF LANDSAT DATA

The need for faster and more economical mapping of water quality and land use has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target categorization and mapping. The categorization techniques (Dye, 1974, 1975; Rogers, 1974, 1975) have been under continued development at Bendix for the past 8 to 10 years, primarily using aircraft multispectral scanner data. More recently, LANDSAT/MSS and Skylab/EREP-S192 data have been used.

BENDIX DATA CENTER

The elements of the Bendix Data Center used to process data for this study are shown in Figure 2 and include: a Bendix Datagrid® Digitizer System 100 for digitizing graphical data, a Bendix Multispectral-Data Analysis System (M-DAS) for the analysis of LANDSAT "computer-compatible tapes" (CCTs), and a Cal Comp Plotter for the production of land-water categorized maps from the processed LANDSAT tapes. A Gerber Series

40 Plotting Table is also used for this mapping function. M-DAS has been discussed (Johnson, 1974) in detail previously.

The nucleus of the M-DAS is a Digital Equipment Corporation PDP-11/35 computer with 28K words of core memory, one 1.5M-word disc pack, two nine-track 800 bit-per-inch (bpi) tape transports, and a DECwriter unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 9 1/2-in. drum recorder for recording imagery on film, and a color moving-window computer-refreshed display. M-DAS is the result of an evolutionary program initiated by Bendix in 1967 and is dedicated to the processing of remote sensing data.

PROCESSING STEPS

The data processing steps used (Figure 2) and the results achieved in transforming LANDSAT CCTs into the desired land-use maps and data are briefly summarized in the following paragraphs.

Establish Map Categories

The first step in the development of the OKI land-use map was to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typified the land-water categories of interest, the "training areas." These areas of known characteristics were established from aerial photographs and ground survey data, and were located on the LANDSAT CCTs by viewing the taped data on the M-DAS TV monitor. The coordinates of the training areas were designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas, typically 20 to 50 pixels in size, were picked for each category, with each pixel corresponding to a ground coverage of 57 x 79 m. The color code was used in later playback of the tapes when the computer-categorized data are displayed in the designated colors.

Develop Processing Coefficients

The LANDSAT spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each target category. The descriptors (Dye, 1974) included the mean signal and standard deviation for each LANDSAT band and the covariance matrix taken about the mean. The descriptors were then used to generate a set of processing coefficients for each category. In automatic-category processing, the coefficients are used by the computer to form a linear combination of the LANDSAT measurements to produce a variable whose amplitude is associated with the probability of the unknown measurement being from the target sought. In category processing, the probability of a LANDSAT pixel arising from each one of the different target categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown (uncategorized).

The categorical processing of multivariate data at Bendix is carried out using a maximum likelihood procedure under multivariate normal hypothesis. The implementation of this procedure (Dye, 1975) for M alternatives involves evaluation of M density equations and acceptance of the alternative with the greatest density. The direct evaluation of each density equation requires (N + 1) times N multiply and add operations if implemented with N original variables. The direct method, thus, is slow and costly. The procedure used at Bendix greatly minimizes the computational load with no sacrifice in computational accuracy. During the decision process, the observation is subjected to a principal component transformation derived for a given group, and another transformation in which the inverse of the covariance matrix is diagonalized with respect to the covariance matrix of the remaining groups. The first transformation gives the direction of maximum variance of the given group with respect to the background (the remaining groups). When the decision process is carried out, the computation for each group now involves only N + 1 add and multiply operations. In addition to the cost-effectiveness, it also permits an increase in absolute accuracy by permitting dimensionality reductions, since an eigen value of less than one from the second transformation only hinders the accuracy of the classification scheme and, hence, the associated components for an eigen value of less than one are rejected during computations.

Evaluate Selection of Training Areas and Processing Coefficients

Before producing categorized data for the entire OKI region, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables and viewing the processed imagery on the M-DAS TV monitor. Selection of training areas, generation of accuracy tables, and evaluation of processing

results through use of computer printouts and the TV monitor were iterative operations. The 10 primary land-use categories listed below, in the order of their potential for discharging natural and human sources of nutrients, resulted from the LANDSAT processing.

- Core City/Industrial - Most dense industrial and commercial area, asphalt, concrete, gravel, etc., 0% vegetation.
- Inner City - Second-most dense industrial and commercial area, 1 to 10% vegetation cover.
- Urban - Third-most dense industrial and commercial area, also includes high-density residential area, 10 to 50% vegetation cover.
- Suburban - Fourth-most dense area, housing, isolated shopping center, greater than 50% vegetation cover.
- Cropland (3 categories).
- Fallow Cropland.
- Rangeland.
- Forestland (Density 1) - Mixed hardwood (deciduous) forest and softwoods.
- Forestland (Density 2) - Mixed hardwoods and softwoods.
- Water (5 categories) - Five categories of water are probably: deep clear; shallow water; and three categories corresponding to different sediment concentrations.

In addition to the 10 major categories noted above, cropland was separated into three crop categories and water into five categories. Ground-truth activities are underway to refine the identification of the crop and water categories.

Evaluation of processed results show that some urban categories become confused with non-urban categories; i.e., core city with water, urban with cropland, etc. However, the errors occur at random spots as "speckles" and, when viewed in context on a map grid, are easily corrected by an interpreter. This points up the additional need to transfer LANDSAT categorized data to a base map.

Generate Categorized LANDSAT Tapes

When satisfied with the categorization accuracy achieved on the land-water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the LANDSAT CCTs covering the OKI region. This step in the categorization processing resulted in new or categorized CCTs, where each LANDSAT pixel was represented by a code designating one of the 16 land-water categories. These 16 categories were merged into the 10 primary categories noted previously and mapped at a scale of 1 in. = 5,000 ft for the OKI region. Computer tabulations were also extracted from the categorized tapes to obtain a quantitative measure of land use within the drainage areas.

Produce Categorized Map Overlays

To produce categorized data that will directly relate to a base map, the categorized CCTs were submitted to a second stage of processing. In this stage, new tapes were generated that had data corrected for earth rotation and a format compatible with a computer-driven Cal-Comp Plotter. These tapes, when played back by the computer, caused overlays of a specified land-water category to be drawn by the plotter (see bottom image in Figure 2) on mylar at a scale specified by the operator. Examples of these mylar drawings over a map of drainage areas near Cincinnati are shown in Figure 3. The examples show core city/industrial, water, and forestland categories at the original scale of 1:120,000. The overlays were photographically enlarged later to the final map scale of 1 in. = 5,000 ft. A diazochrome material was exposed through the black and clear category transparencies by a lithographic plate burner and ammonia developed to produce color-coded overlays. The color coding permitted multiple overlays to be used simultaneously over the base map.

A 10-category color coded land-use map was developed for the entire 7,024 sq km (2,712 sq mi) region at the full LANDSAT resolution (0.44 hectare or 1.1 acre pixels) and at a scale of 1 in. = 5,000 ft. The cost for this map was approximately $2.50 per square mile.

Four parameters were used in performing the geometric correction of LANDSAT data: spacecraft heading, spacecraft earth latitude, adjusted scan line length, and spacecraft altitude. The first three parameters only were available on the LANDSAT CCT. The heading, latitude, and adjusted scan line length were used to generate incremental coordinate translations of the LANDSAT data, scan line by scan line, to obtain along-track and cross-track corrections. The coordinate translation increases as the computer moves through the tape, and the rate of increase is a function primarily of spacecraft latitude. Provisions were made to vary the coordinate translation with adjusted scan line length, but experience has shown that the scan line

length varies little and the correction for scan line length has little effect on the data. An important parameter that was not on the tape is exact satellite altitude. This information is available in the Goddard processing facility when the tape is generated, but for some reason it is not placed on the tape. Bendix has attempted to establish a channel through which this information can be made available for tapes delivered to Bendix, but has been unsuccessful to date. Altitude variations can cause approximately $\pm 0.5\%$ variation in the cross-track scale and must be corrected. The approach used by Bendix was to generate one trial overlay (such as water boundaries) after all other corrections are made, overlay the trial overlay on a map, select at least two control points common to both the overlay and the map, and calculate a cross-track correction factor to compensate for satellite altitude variations.

Area Measurement Tables

Computer-generated area measurement tables, illustrated in Figure 4, were produced from the categorized data tapes to determine land use within the drainage areas. To accomplish this step, a procedure was developed by which the drainage area boundaries in earth coordinates (latitude and longitude) are first digitized (Figure 2) from watershed maps. The resulting digital tape is processed on M-DAS (Figure 2) to transform the earth coordinates to LANDSAT coordinates and to extract and tabulate land use from the categorized tape. The area measurement table provides the amount of land that falls within a particular category in terms of square kilometers, acres, and percentage of the total drainage area processed. These data provided a direct and useful input to OKI's water quality model where each category is assigned a "loading function" or pollution equivalent (EPA-1430, 1973). Eventually, by multiplying the extent of land use acreage in an area by these loading functions, the water quality model will calculate the extent of pollution emanating from these non-point sources.

Earth to ERTS Coordinate Transformation - There were three basic steps involved in the automatic referencing of ground coordinates to LANDSAT coordinates. The first step consisted of automatic retrieval of the latitude and longitude of carefully selected ground control points (GCPs) from a map through a digitizing process. The criteria for selecting these GCPs is that they can be easily and accurately identified on LANDSAT imagery. The second step consisted of converting the latitude and longitude of these GCPs to LANDSAT coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. The approximately-derived LANDSAT coordinates and transformation are used, however, to identify the actual LANDSAT coordinates associated with the GCPs. To accomplish this, the coordinates of a GCP is input to the Bendix M-DAS. The approximate transformation computes the LANDSAT coordinates and displays the area on the TV monitor. Positional errors of the GCPs displayed to the operator are designated by a cursor to the computer, which uses the error measurement to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional GCPs until the desired geometric accuracy is achieved. This rapid interactive procedure is essential for producing a transformation matrix that provides an accurate transformation of earth to LANDSAT coordinates.

CONCLUSION

Machine processing of LANDSAT data provides a rapid and economical means of mapping land use in watersheds of lakes and rivers.

Although additional improvements can and are being made in processing techniques to increase mapping rates and accuracy and to reduce cost, OKI has demonstrated the techniques and utility of LANDSAT for mapping watershed land use on an operational basis.

As there is still some confusion between some urban and non-urban categories as indicated by random misclassification (speckling), additional processing refinements are needed to improve separability of these categories.

Machine-assisted interpretation of LANDSAT tapes was found to be very fast. The analysis phase required about one day per LANDSAT scene. Once the analysis was completed and the processing coefficients were computed, the categorized tape was produced for a full LANDSAT CCT (2,500 square nautical miles) in less than 30 minutes. Boundaries of water drainage areas were manually digitized from maps of the OKI area at a rate of about six per hour. The computer extracted and tabulated land use within these areas at a rate of one every 3 minutes. The major time-consuming step in the production of the LANDSAT products was the generation of the map overlays for the region, which required about 3 weeks. In the near future, equipment and techniques will be in use that will permit this step to be accomplished within a day.

The machine-processing techniques permitted the nine-county OKI region to be mapped to 1-acre

detail for $20,000. With application of conventional techniques, it is not uncommon for a county to spend this much or more to map similar categories within a much smaller area. Additionally, conventional techniques based on manual interpretation of photography and field checks typically require a year or two to obtain a mapping product similar to that obtained by OKI within 90 days.

REFERENCES

Dye, R. H., "Multivariate Categorical Analysis," Bendix Special Report BSR 4149, 1974.

Dye, R. H. and C. S. Chen, "Divergence Analysis of Bendix Feature Extraction Classification System," Proceedings of Purdue Symposium on Machine Processing of Remotely Sensed Data, June 3-5, 1975.

Johnson, R. H., "M-DAS Multispectral Data Analysis System," Bendix Report BSR 4146B, September 1974.

Ohio-Kentucky-Indiana Regional Council of Governments, "Clean Water; What You Can Do," October 1974.

Rogers, R. H., Reed, L. E., and N. J. Shah, "Automatic Classification of Eutrophication of Inland Lakes from Spacecraft Data," Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Vol. II, April 1974.

Rogers, R. H., Reed, L. E., Shah, N. J., and V. E. Smith, "Computer Mapping of Turbidity and Circulation Patterns in Saginaw Bay, Michigan (Lake Huron) from ERTS Data," Proceedings of ASP-ACSM Convention at Washington, D. C., March 1975.

US Environmental Protection Agency, Office of Air and Water Programs, EPA-430/9-73-014, "Methods for Identification and Evaluation of the Nature and Extent of Non-Point Sources of Pollutants," October 1973.

US Environmental Protection Agency, Water Planning Division, (Draft) "Guidelines for Areawide Waste Water Treatment Management," May 1974.

Figure 1. LANDSAT Band 7 Image (E-1265-15485) of 14 April 1973 Showing the Ohio-Kentucky-Indiana Regional Council of Governments Area.

ORIGINAL PAGE IS
OF POOR QUALITY

Develop Earth to LANDSAT Coordinate Transformation

- Digitize Ground Control Points
- Designate Location of Training Areas
- Digitize Boundaries of Areas for which Area Printout Tables Are Required; Watersheds, Counties, Townships, etc.

Produce LANDSAT Categorized Tapes

- Define Land-Water Categories and Locate Corresponding Training Areas within LANDSAT Tapes.
- Compute Category Characteristics.
- Evaluate Training Area Selection.
- Transform LANDSAT Tapes into New Set of Tapes where Each Pixel Is Coded to Correspond to Interpreted Land-Water Categories.

Generate Data and Map Products from LANDSAT Categorized Tapes

- Produce Transparent Color-Coded Overlay for Each Category; Typical Scales of 1:24,000, 1:62,500, and 1:250,000.
- Generate Color-Coded Imagery Where Color Is Used as a Code to Designate Categories.
- Produce Tabular Computer Printouts Listing Area Covered by Land-Water Categories within Specified Political and Geographic Boundaries in Percent Coverage per Category, Acres, and Square Kilometers.

Figure 2. Machine Processing of LANDSAT Data.

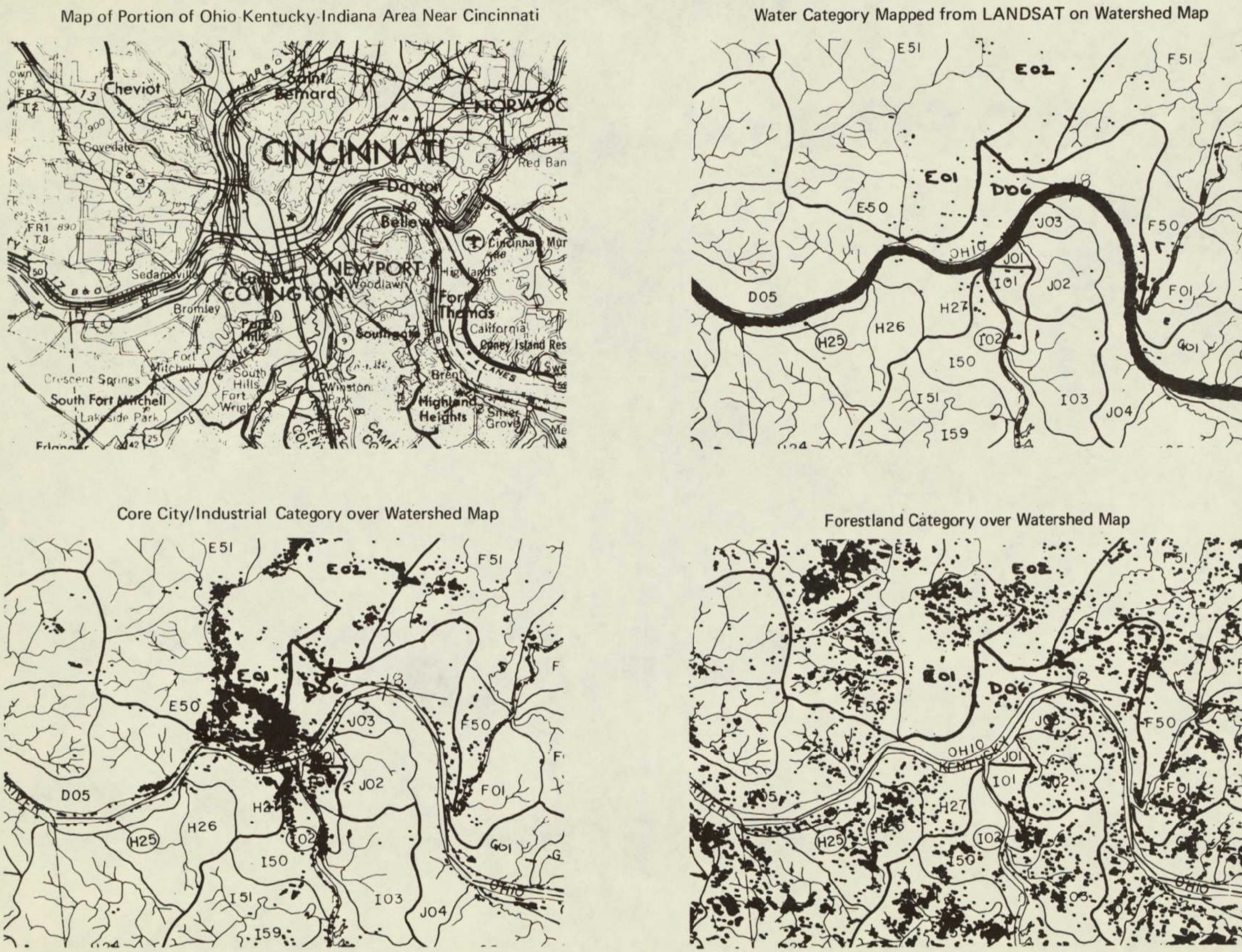
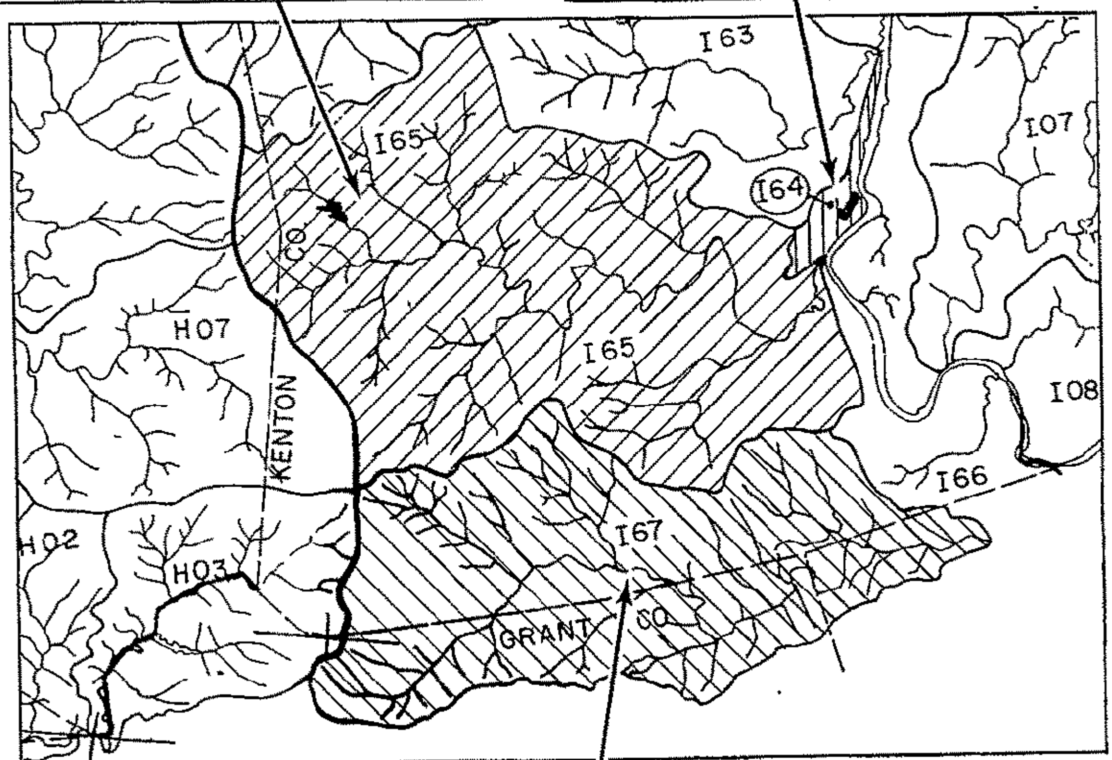


Figure 3. Examples of Land Use Mapped from LANDSAT Categorized Tapes (Original Scale: 1 inch = 2 miles).

Category	Percent of Watershed	Acres	Square Kilometers
Core City/Industrial	0.06	12.30	0.05
Inner City	0.14	27.95	0.11
Urban	5.97	1,200.62	4.86
Suburban	0.83	167.68	0.68
Cropland	2.16	435.98	1.76
Fallow Cropland	29.41	5,914.78	23.94
Rangeland	29.77	5,986.33	24.23
Forestland 1	13.23	2,660.59	10.77
Forestland 2	18.01	3,620.86	14.65
Water	0.03	4.47	0.01
Uncategorized	0.38	77.14	0.32
Total	100	20,108.70	81.38

Category	Percent of Watershed	Acres	Square Kilometers
Core City/Industrial	0.16	1.12	0.0
Inner City	0.16	1.12	0.0
Urban	8.2	58.13	0.24
Suburban	0.16	1.12	0.0
Cropland	1.73	12.29	0.05
Fallow Cropland	19.87	140.85	0.57
Rangeland	20.98	148.68	0.60
Forestland 1	24.45	173.27	0.70
Forestland 2	23.82	168.80	0.68
Water	0	0	0
Uncategorized	0.47	3.35	0.01
Total	100	708.75	2.87



Category	Percent of Watershed	Acres	Square Kilometers
Core City/Industrial	0.01	1.12	0.0
Inner City	0.01	1.12	0.0
Urban	6.58	960.27	3.89
Suburban	0.77	112.91	0.46
Cropland	1.59	231.41	0.94
Fallow Cropland	27.96	4,082.55	16.52
Rangeland	27.56	4,024.42	16.29
Forestland 1	13.01	1,900.42	7.69
Forestland 2	22.31	3,258.66	13.19
Water	0	0	0
Uncategorized	0.21	30.19	0.12
Total	100	14,603.07	59.10

Figure 4. Map of Watersheds in Southern Kenton County, Kentucky, and Tabular Printouts Produced from LANDSAT Categorized Tapes.